

# Phase-enhanced Defect Sensitivity for EUV Mask Inspection

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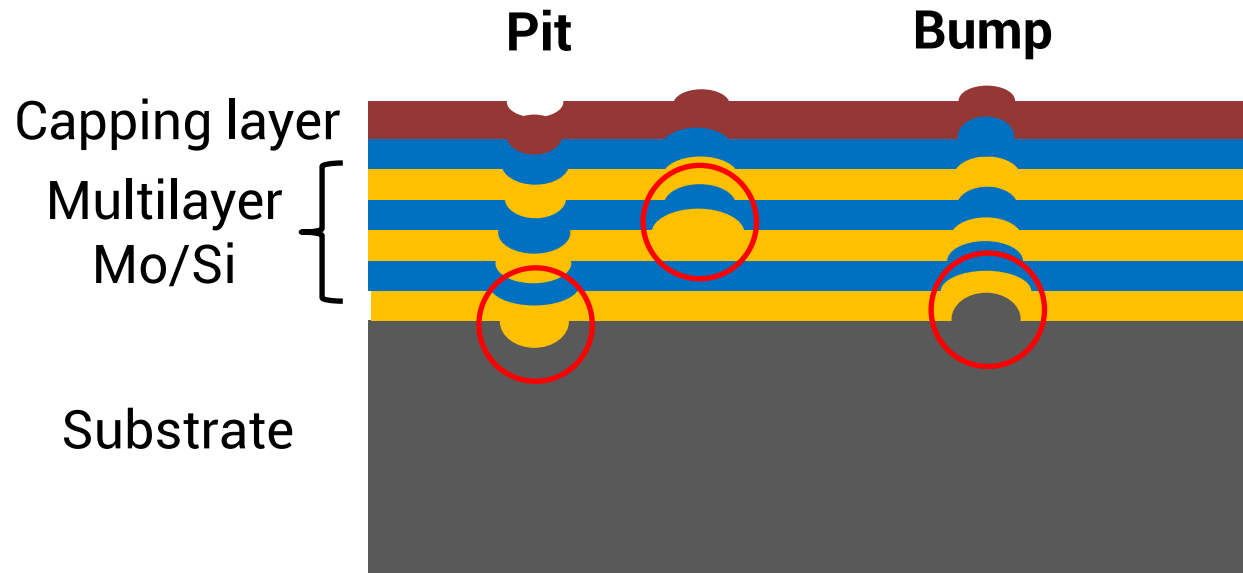
# Big picture

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- Demonstration of Zernike phase contrast method on SHARP EUV microscope will be presented.
  - Zernike phase contrast method can get better phase defect sensitivity at focus.
  - Apodization in the pupil plane can mitigate the speckle noise and improve the SNR of the defect measurement.

# Motivation

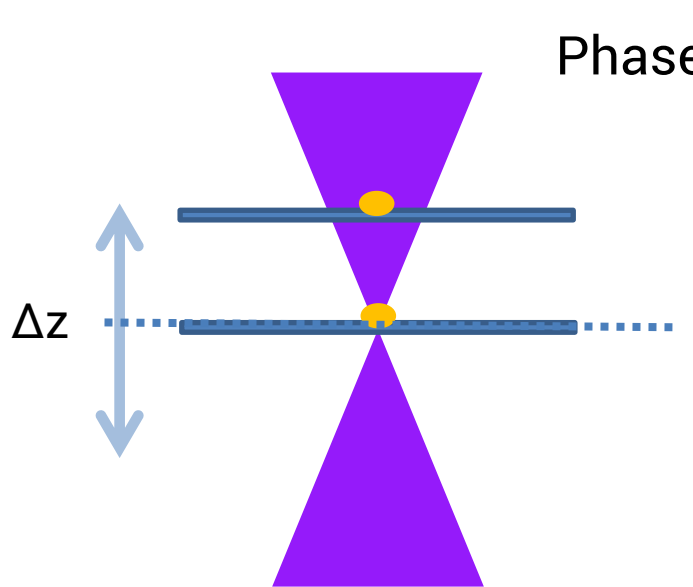
- Defect-free EUV mask is needed for the industry:
  - Problem: Phase defect on EUV mask is invisible at focus.
    - Current solution: Through-focus inspection.
    - New solution: **Zernike phase contrast microscope.**



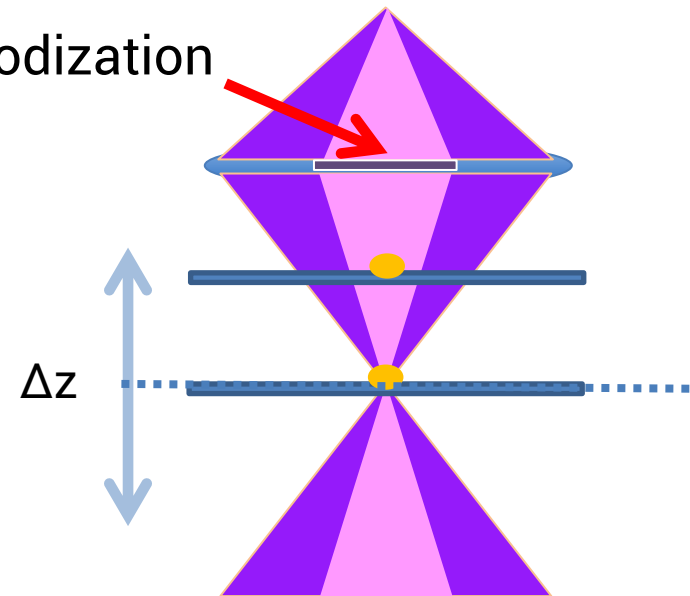
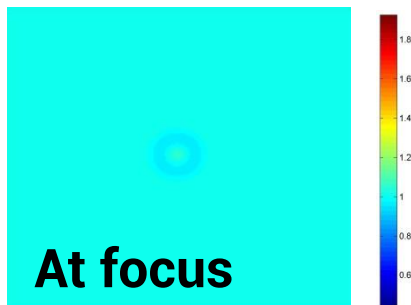
# Zernike phase contrast method: *Single scan at focus with better defect sensitivity*

Conventional microscope

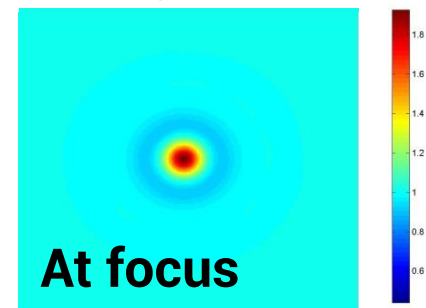
Zernike phase contrast microscope



Aerial image of the mask



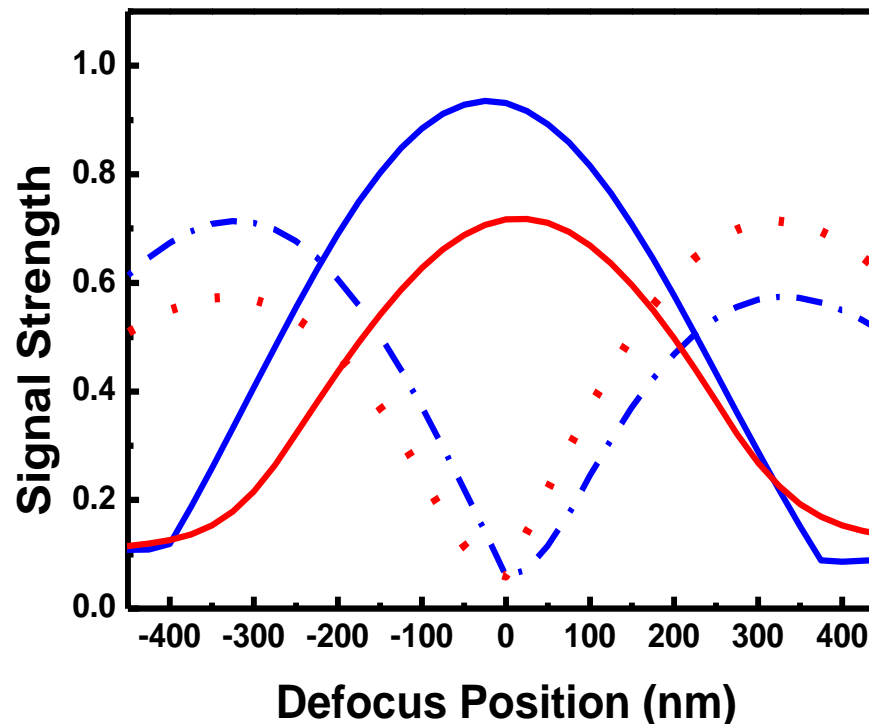
Aerial image of the mask



# Simulation verification:

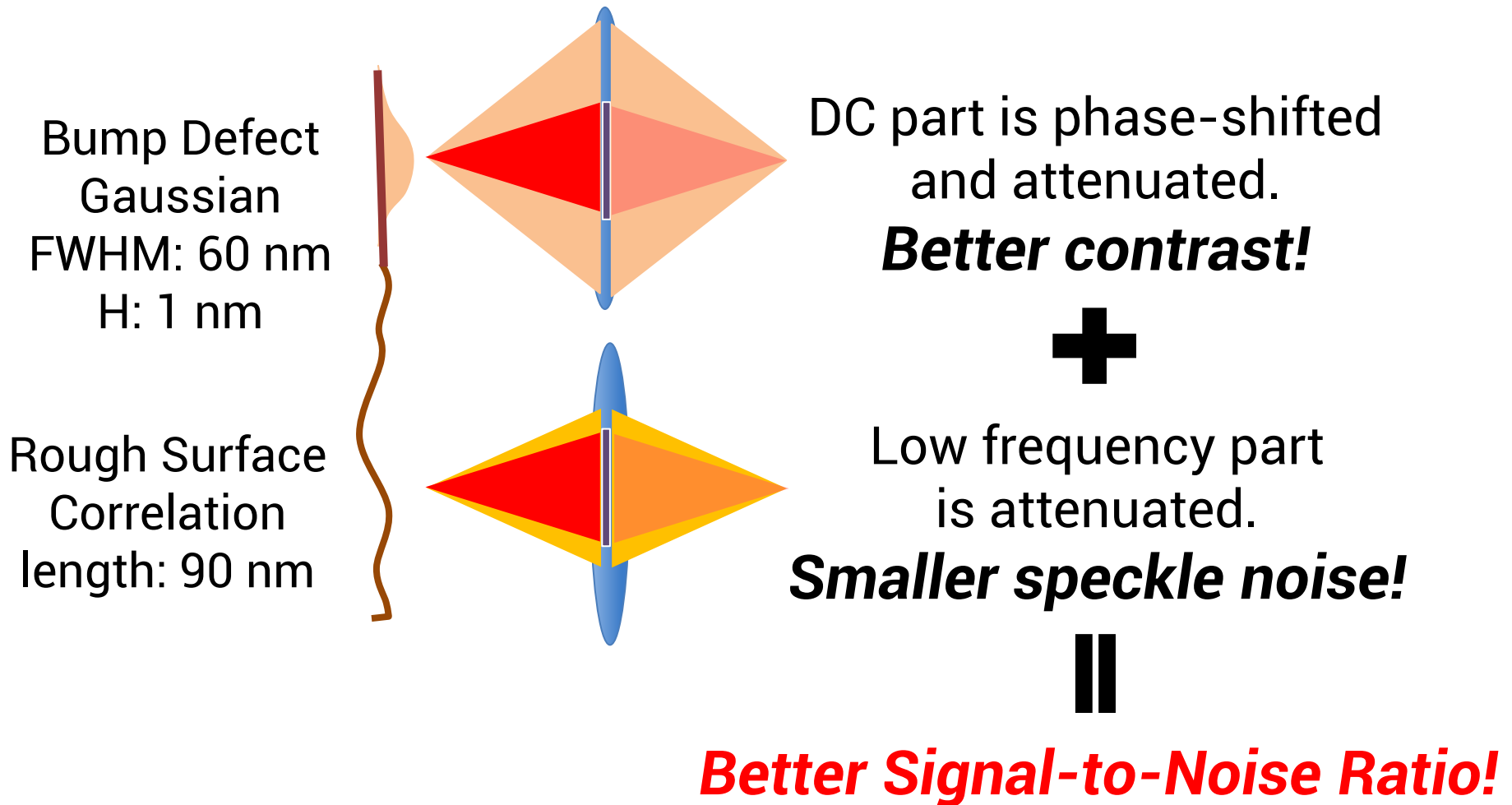
## *In-focus inspection with larger defect signal*

— Pit (Phase contrast method)      - - - Pit (Conventional method)  
— Bump (Phase contrast method)      - · - Bump (Conventional method)



- Defect Type: *Height* = 1nm. *FWHM* = 60nm.
- Illumination: *NA* = 0.2, *Sigma*: 0.5.

# Phase shift + Apodization = Better SNR!



# Simulation verification:

## *Better SNR with phase contrast & apodization*

	Conventional Microscope	Phase Contrast Microscope	Phase Contrast+ Apodization Microscope
SNR at Focus	1.08	7.63	21.17

- Defect Type: *Bump. Height = 1nm. FWHM = 60nm. Roughness: 77pm. System noise: 5%.*
- Illumination: *NA= 0.2, Sigma: 0.5.*

# SEMATECH zoneplate mask inspection microscope

- Source: Synchrotron
- Optics: Zoneplate-lenses
- 4xNA: 0.25 – 0.625
- Sigma: Programmable

***Customize design features  
(Phase shift/Apodization)  
on zoneplates!***



# Customized zoneplates

Standard

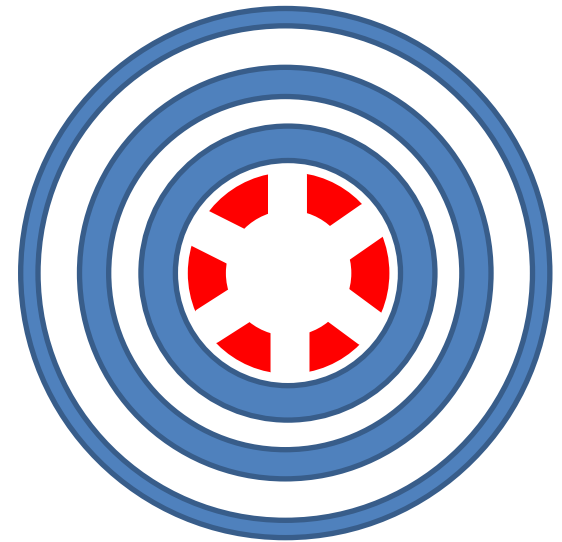


Phase contrast



Offset zones to create  
phase-shift.

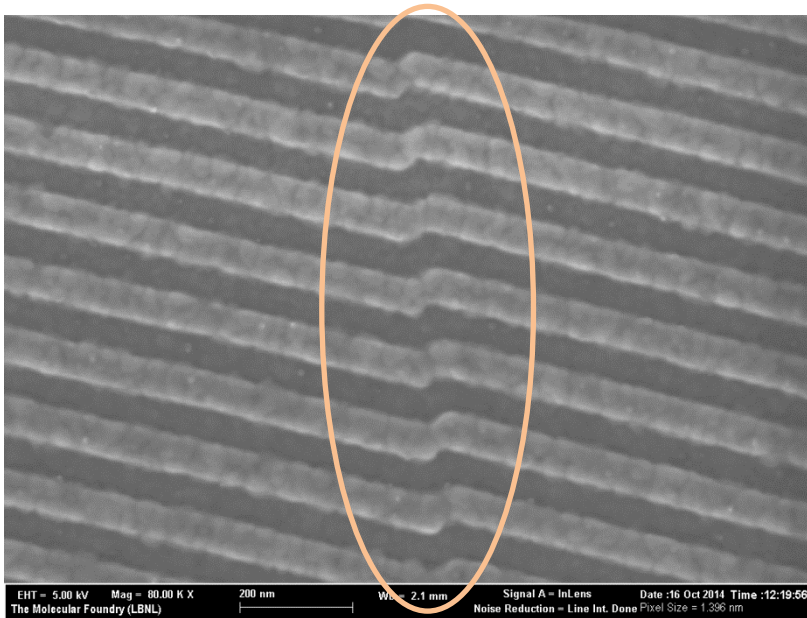
Phase contrast  
+ Apodization



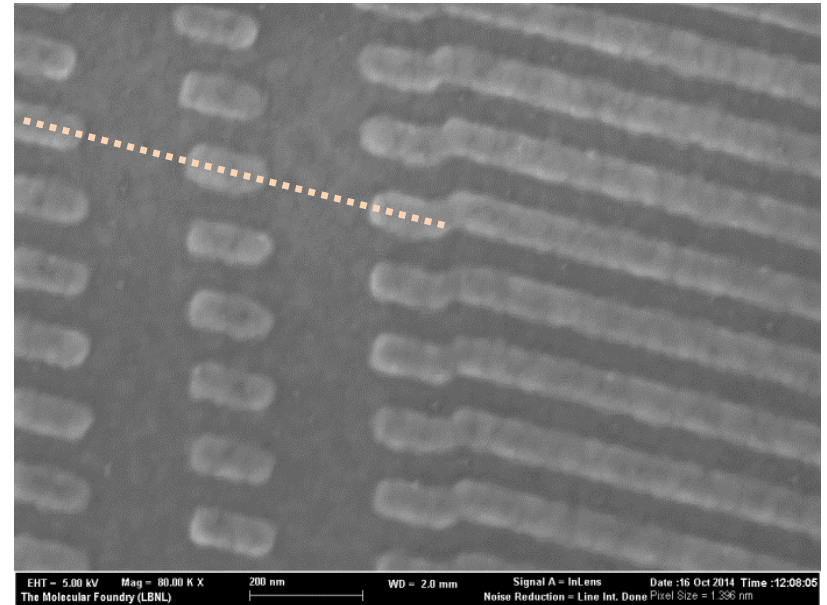
Control angular  
duty cycle to reduce  
transmission.

# SEM images of zoneplates:

## Different designs on zoneplates



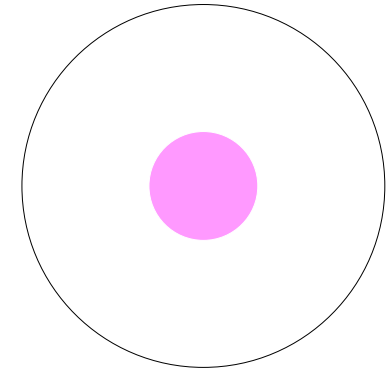
➤ Phase shift zoneplate



➤ Phase shift with **apodization** zoneplate

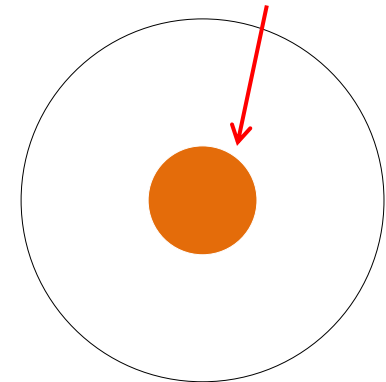
# Experiment parameters

- 4xNA: **0.33**.
- Sigma: **0.3 (Disk)** .
- Phase shift:
  - **0°** for standard zoneplate.
  - **90°** for phase contrast zoneplate.
- Apodization:
  - **23% intensity transmission**.
- Mask: provided by **Global Foundries**.
- Defect : **Native defect** on the substrate.



*Disk Illumination*

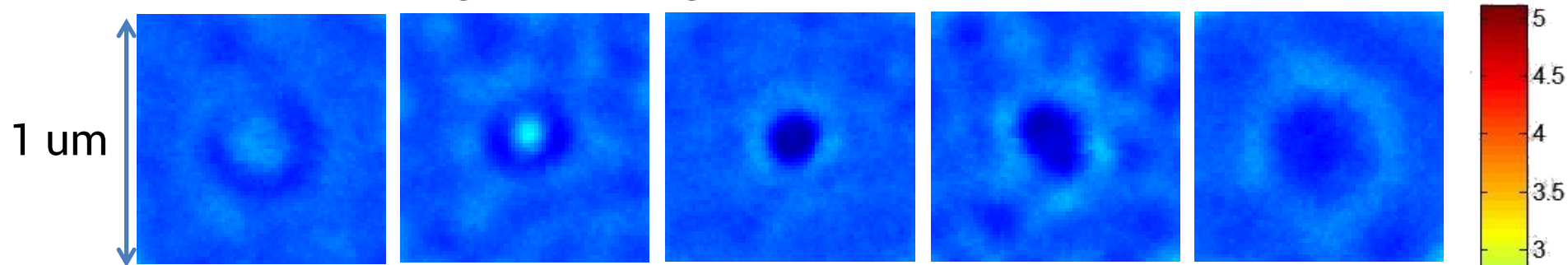
Phase shift/apodization



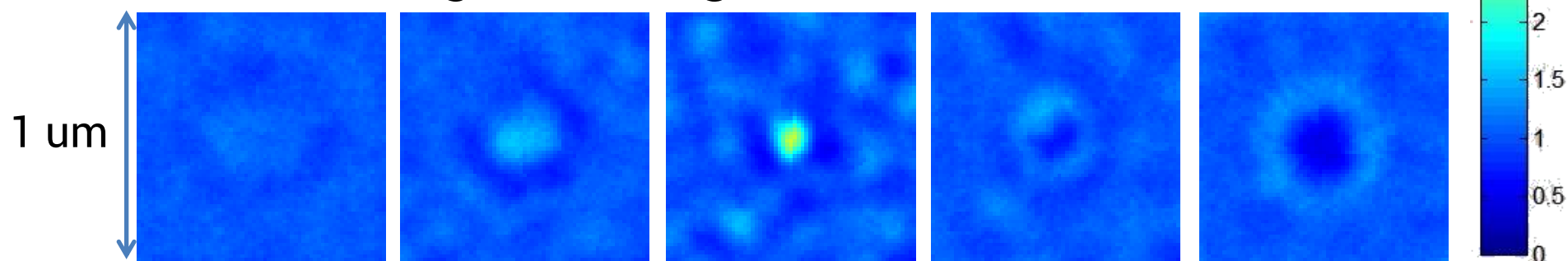
*Pupil*

# Aerial images comparison: Conventional vs. Phase contrast

0.3 sigma, 0 degree, 100% transmission



0.3 sigma, 90 degree, 100% transmission

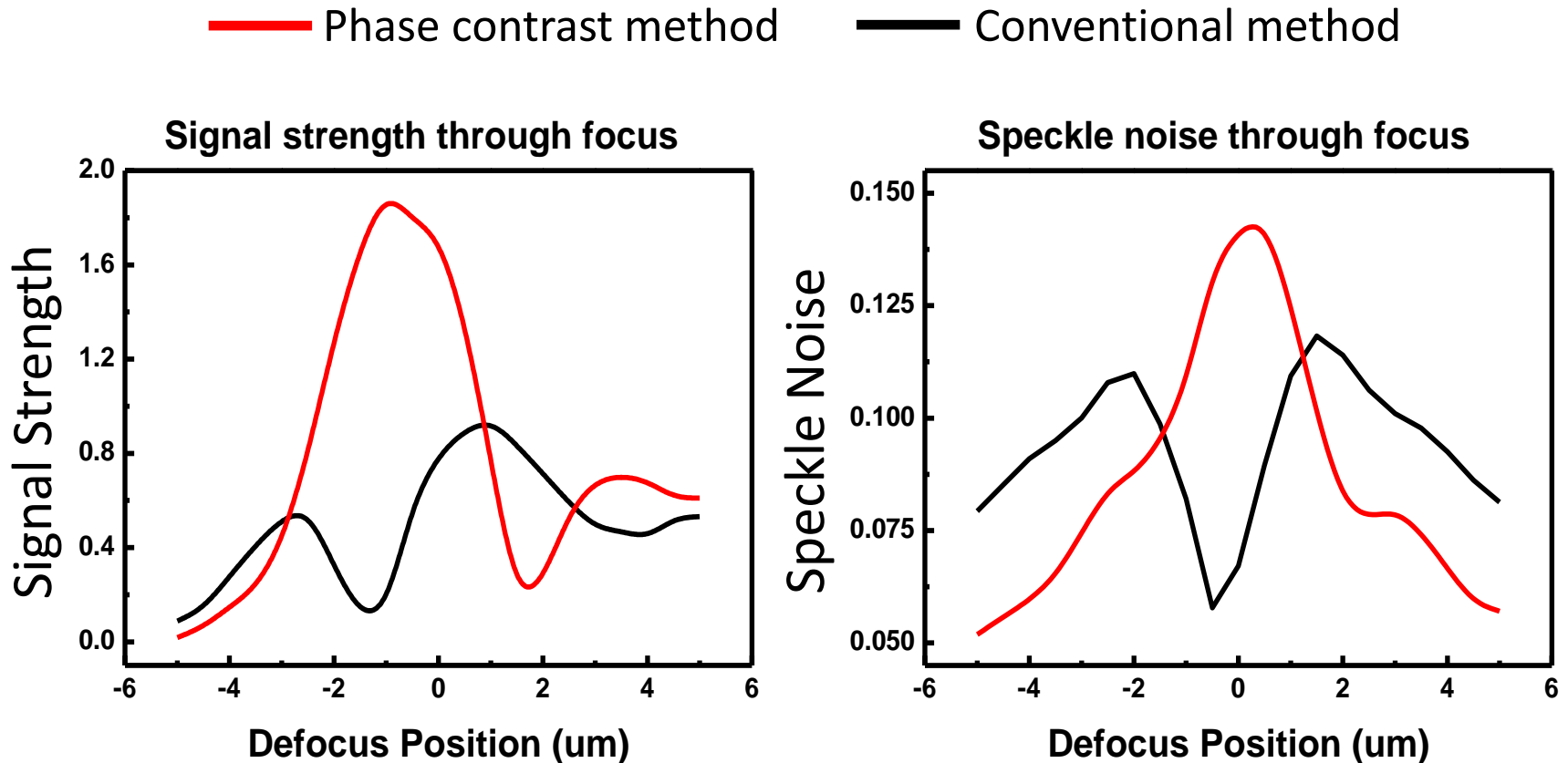


-5  $\mu\text{m}$  Defocus Position 5  $\mu\text{m}$

A horizontal axis at the bottom indicates the Defocus Position, ranging from -5  $\mu\text{m}$  to 5  $\mu\text{m}$ . The five images in each row correspond to defocus positions of approximately -5, -2.5, 0, 2.5, and 5  $\mu\text{m}$ .

**Larger defect signal at focus by phase contrast method!**

# Larger defect signal at focus by phase contrast method

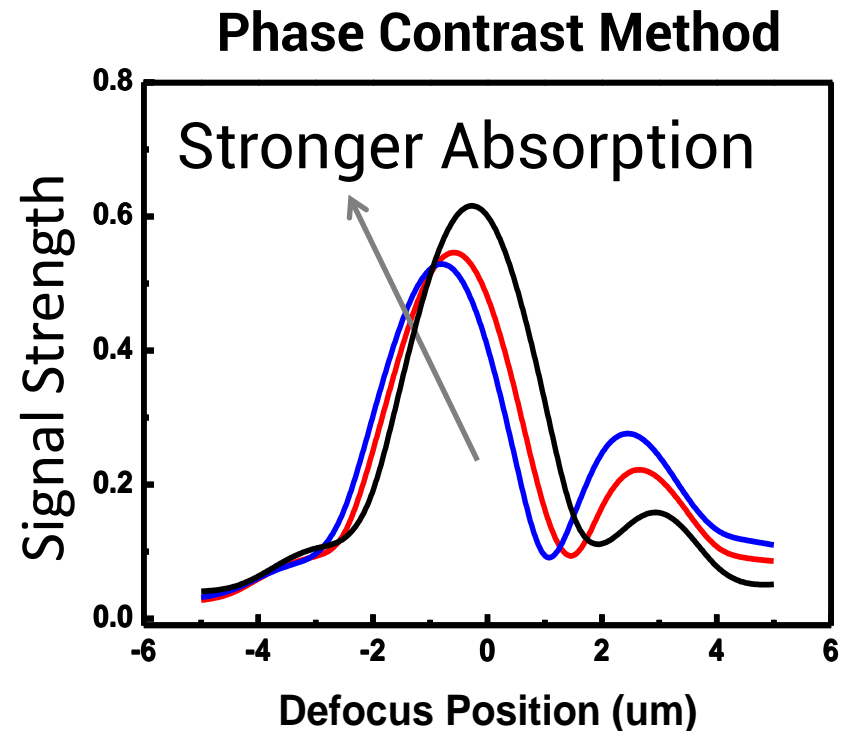
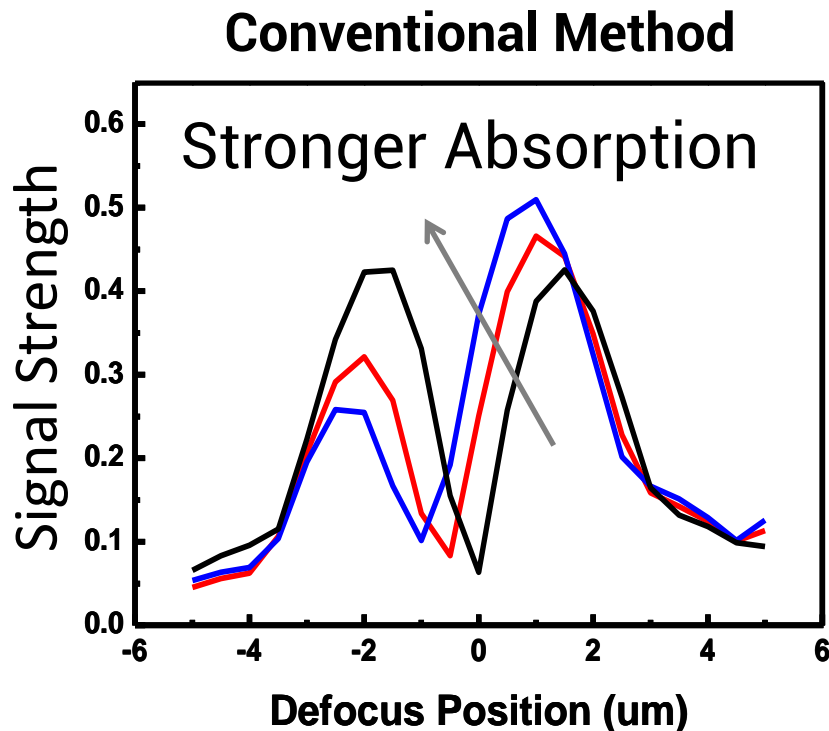


- Defect Type: *Native defect on the surface.*
- Illumination:  $NA = 0.33$  (4x),  $\Sigma: 0.3$ .

# Simulation verification:

## *Asymmetric through-focus behavior by native defect*

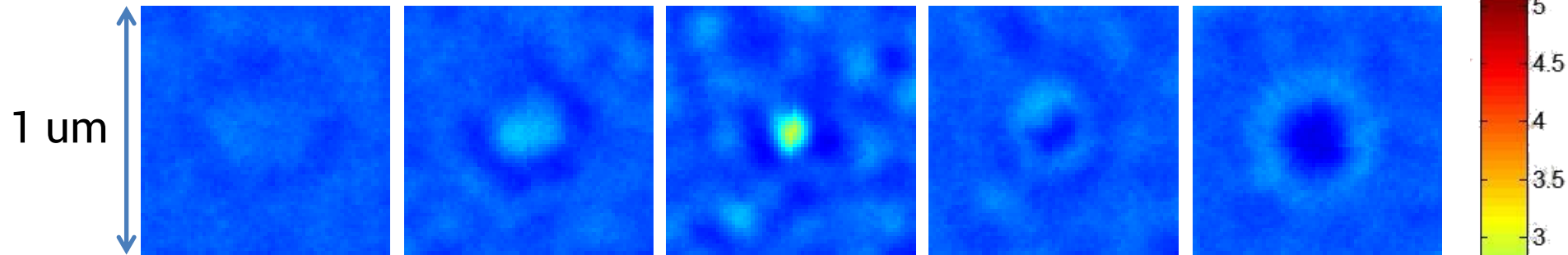
— Phase/Amplitude defect I      — Phase defect  
— Phase/Amplitude defect II



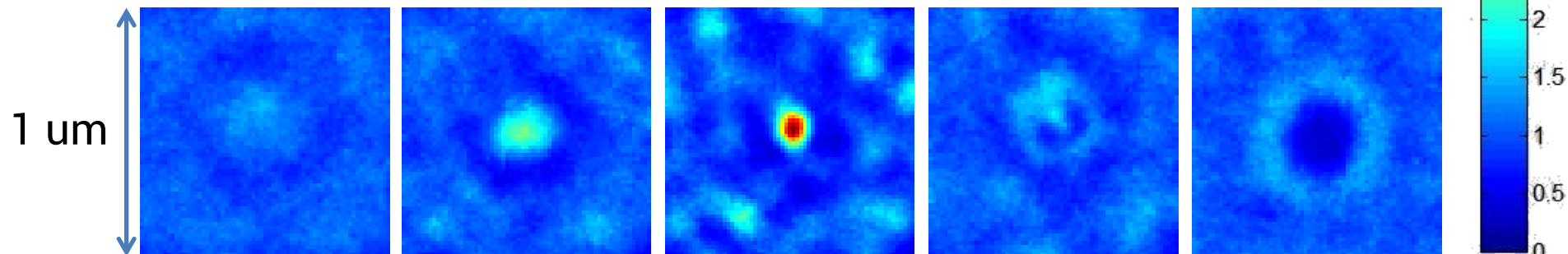
- Defect Type: *Bump*. Height = 1nm. FWHM = 60nm.
- Illumination: NA= 0.0825 (1x), Sigma: 0.3.

# Aerial images comparison: Phase contrast vs. Phase contrast + Apodization

0.3 sigma, 90 degree, 100% transmission



0.3 sigma, 90 degree, 23% transmission



-5  $\mu\text{m}$  Defocus Position 5  $\mu\text{m}$

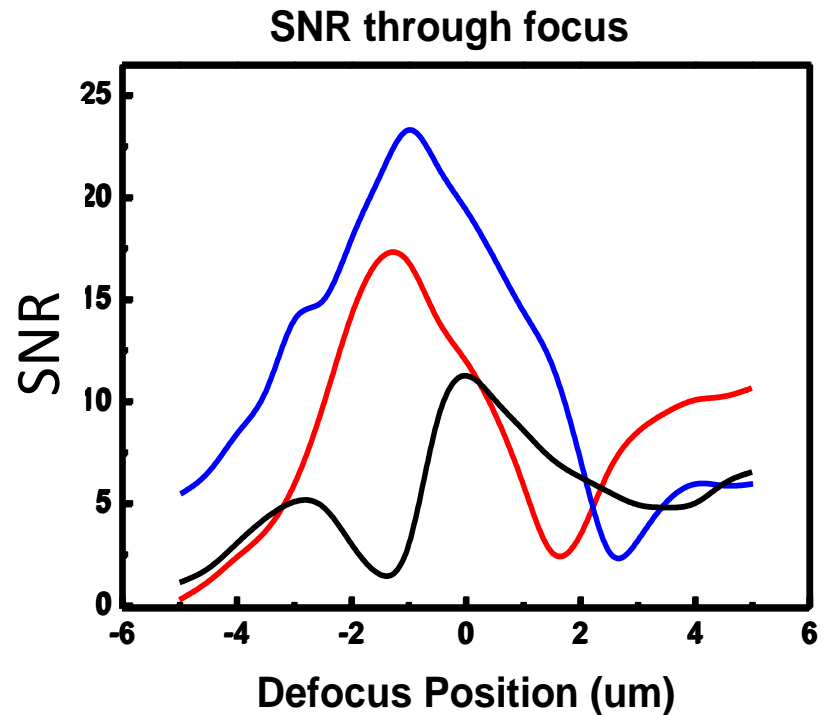
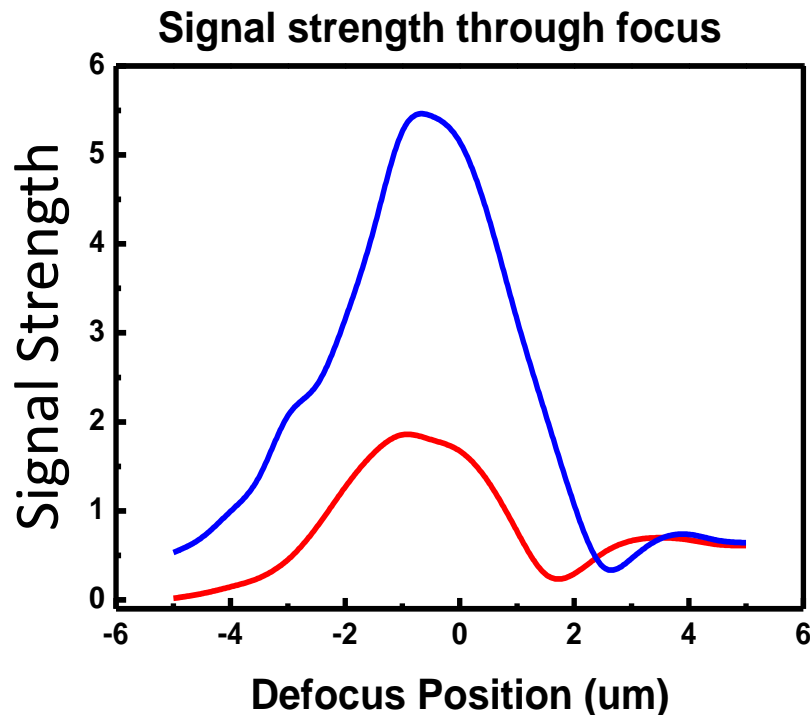
**3-fold enhancement on defect signal by  
phase contrast and apodization.**

# Larger defect signal and better SNR at focus by phase contrast with apodization method

— Phase contrast method

— Conventional method

— Phase contrast with apodization method



- Defect Type: *Native defect on the surface.*
- Illumination:  $NA = 0.33$  (4x),  $\Sigma = 0.3$ .

## Table I: With or without apodization

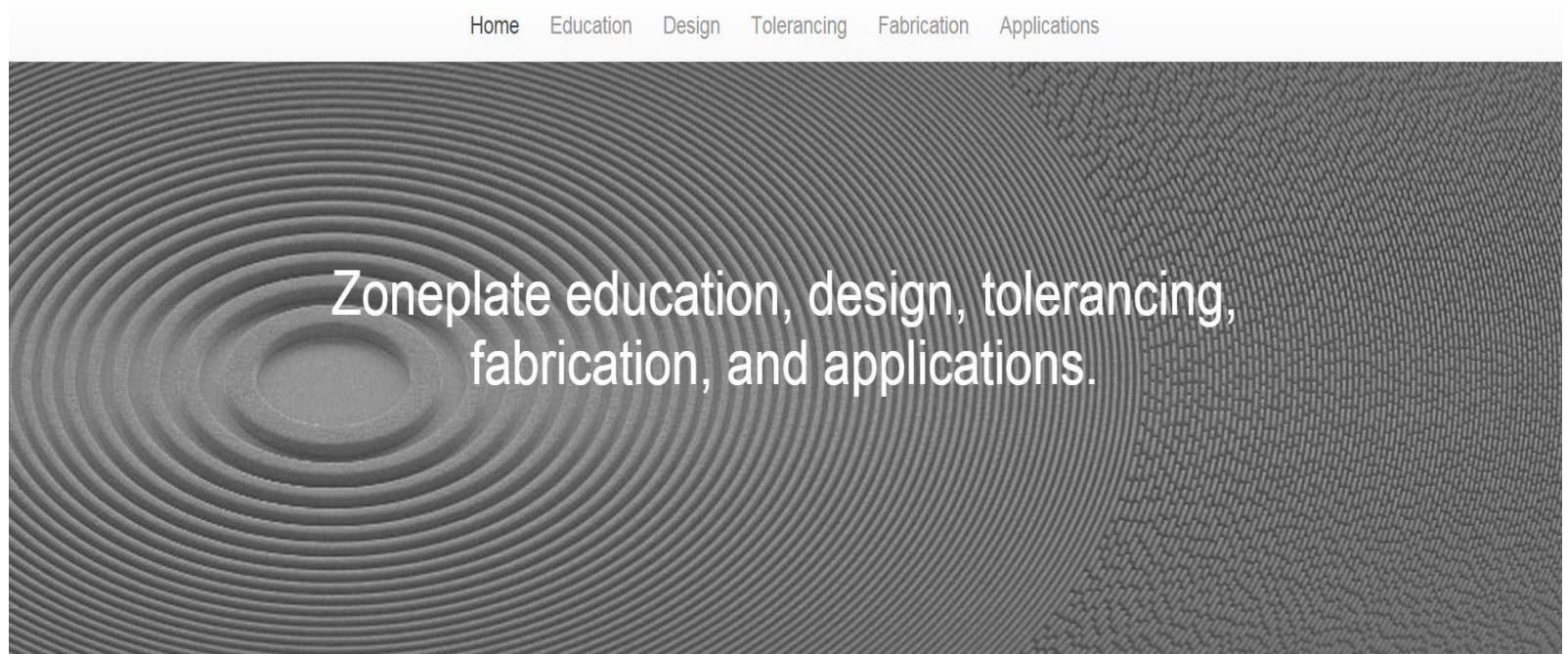
	a) 90 degree <b>100%</b> transmission	b) 90 degree <b>24%</b> transmission	Ratio (b/a)
Reference Intensity (Unit: counts)	5951.6	1359.7	<b>0.23</b>
Speckle Noise (Normalized to 5951.6)	0.141	0.062	<b>0.44</b>
Defect Signal (Normalized to 5951.6)	1.72	1.20	<b>0.70</b>
SNR at Focus	12.2	19.4	<b>1.59</b>

**The reduction of speckle noise improves the defect SNR!**

## Table II: SNR by experiment result

	Conventional Microscope	Phase Contrast Microscope	Phase Contrast+ Apodization Microscope
SNR at Focus	11.8	12.2	19.4
Peak SNR	11.8 ( $\Delta z = 0 \text{ um}$ )	17.5 ( $\Delta z = -1.0 \text{ um}$ )	24.38 ( $\Delta z = -1.0 \text{ um}$ )

- Defect Type: *Native defect on the surface.*
- Illumination: *NA = 0.33 (4x), Sigma: 0.3.*



# Summary

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- In-focus inspection of native defect has been demonstrated on SHARP EUV microscope by phase contrast method.
- Phase contrast method can improve the defect sensitivity at focus for defect with both phase/amplitude features.
- Native defect SNR can reach 20 at focus by adding phase shift and reducing transmission in the pupil.

# Acknowledgement

➤ UC Berkeley:

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# Thanks for your attention!

